

REMARKS

Favorable reconsideration of this application is respectfully requested in view of the following remarks.

By way of this Amendment, Claims 1-4, 6-11, 13, 14 and 16-20 are canceled and new Claims 21-40 are presented for consideration. Claims 5, 12 and 15 were previously canceled.

As explained in earlier responses filed in this application, the subject matter of this application pertains to a fuel cell module, a fuel cell arrangement, and process for producing a fuel cell module for a fuel cell arrangement. As is known in the art, fuel cell modules are typically comprised of two electrodes (sometimes referred to by others as separators), a pair of catalyst plates positioned between the two electrodes, and a membrane positioned between the two catalyst plates.

In the fuel cell module, fuel cell arrangement and process at issue here, the electrode (electrodes) is comprised of two plates that are at least partially joined or held together by a common seal element. The present application describes and illustrates that the seal element which at least partially joins or holds together the two plates defining each electrode can take various forms and can be integrated with respect to the two plates in different ways.

By constructing the electrode (electrodes) in this way, it is possible to impart a desired surface topography on each side of the plate relatively easily by stamping or embossing the plates, if desired. When the electrode is in the form of a single plate, this is not possible as the negative of the embossment will occur on the opposite side of the electrode. Thus, with a single plate electrode structure, surface

topography must be imparted to the electrode surfaces in a different way such as through milling.

It is understood from the various rejections set forth in the most recent Official Action that the previously presented claims are being broadly interpreted, and are being interpreted in a manner not consistent with the intended wording. That is, the cited references do not actually disclose that the electrode of a fuel cell module (or respective electrodes of a fuel cell arrangement) should be constructed as two separate plates at least partially joined or held together by a common seal element.

To better define the subject matter at issue here, the previously presented claims are canceled, and new Claims 21-40 are presented for consideration. The new claims include independent Claims 21, 25, 27, 39 and 40. Independent Claims 21 and 25 define a fuel cell arrangement, independent Claims 27 and 39 recite a fuel cell module, and Claim 40 is directed to a process for producing a fuel cell module for a fuel cell arrangement. Each of the independent claims defines, in combination with the other claimed features, the electrode (electrodes) and further recites that the electrode (electrodes) is comprised of two separate plates at least partially joined or held together by a common seal element. In addition, each independent claim is worded to make more clear what constitutes the claimed "electrode." In this regard, each independent claim recites that there are no catalyst plates between the two plates forming the electrode.

Thus, independent Claim 21 defines that the fuel cell arrangement comprises first, second and third electrodes, with each electrode being comprised of two separate plates held together by a common seal element of polymer material extending through respective openings in the plates. The present application

describes and illustrates (e.g., in Figs. 2 and 4-10) various versions of the common seal element that extends through respective holes in the separate plates forming a single electrode. Independent Claim 21 also recites the pair of catalyst plates positioned between adjacent electrodes, and the membrane position between adjacent pairs of catalyst plates. Further, Claim 21 defines that there are no catalyst plates and no membranes positioned between the two plates forming each respective electrode. Various drawing figures in this application such as Fig. 2 illustrate the absence of catalyst plates and membranes between the two plates forming respective electrodes.

New independent Claim 25 also defines first, second and third electrodes, with a pair of catalysts plates positioned between adjacent electrodes, and a respective membrane positioned between adjacent catalyst plates. This claim also defines that each of the electrodes is comprised of two separate plates held together by a common sealing element, wherein the common sealing element encompass at least a portion of the end face of the two plates and extends onto surfaces of the two plates that face away from one another. This arrangement of the common seal element relative to the two plates forming each electrode is illustrated by way of example in Fig. 3 and is described in the specification. Claim 25 also sets forth that there are no catalyst plates and no membranes positioned between the two plates forming each respective electrode.

Independent Claim 27 defines that the fuel cell module comprises an electrode in which two separate plates are at least partially joined together by a common seal element, with a catalyst plate in contact with one surface of each plate. The claim additionally recites that each of the plates forming the electrode is

provided with an opening, and that the common seal element extends through the opening in each plate. Claim 27 further recites that there are no catalyst plates positioned between the two plates forming the electrode.

Independent Claim 39 also recites that the fuel cell module comprises an electrode in which two separate plates are at least partially joined together by a common seal element, with a catalyst plate in contact with one surface of each plate. As claimed, the common sealing element encompasses at least a portion of the end face of each plate and extends onto surfaces of the two plates that face away from one another. The claim further recites the absence of catalyst plates between the two plates forming the electrode.

Finally, Claim 40 recites a process for producing a fuel cell module for a fuel cell arrangement that involves inserting at least portions of two separate plates each provided with an opening into a casting mold, filling the casting mold with a polymer seal material so that the seal material adjoins the first and second plates and extends through the opening in each plate to form a single electrode of the fuel cell module for the fuel cell arrangement, and directly contacting respective surfaces of the two plates that face away from one another with respective catalyst plate, wherein there are no catalyst plates between the surfaces of the plates that face one another.

Turning now to the various references cited in the most recent Official Action, *Japanese Application Publication No. 2001-338673* discloses a fuel cell separator assembly seal structure in which two electrodes or separators 1, 2 are connected by way of an injection molded material 19. A positive electrode 5 and a negative electrode 6 are positioned between the two electrodes or separators 1, 2, and an

electrolyte membrane 4 is positioned between the positive and negative electrodes 5, 6.

Thus, this reference discloses connecting together two electrodes by way of a molding material 19. However, the '673 *Japanese application publication* does not disclose that each electrode is made of two plates which are at least partially joined or held together by a molding material. More specifically, the two separators (electrodes) 1, 2 disclosed in the '673 *Japanese application publication* cannot correspond to the two plates forming the electrode as recited in independent Claims 21, 25, 27 and 39 of this application because of the positive and negative electrodes 5, 6 (i.e., catalyst plates) that are positioned between the two separators 1, 2. As mentioned above, the independent claims in this application recite that there are no catalyst plates between the facing surfaces of the two plates forming the electrode.

In addition, the '673 *Japanese application publication* does not disclose a process for producing a fuel cell module as recited in Claim 40 that involves inserting at least portions of two separate plates each provided with an opening into a casting mold, filling the casting mold with a polymer seal material so that the seal material adjoins the first and second plates and forms a common seal element extending through the opening in each plate to produce a single electrode of the fuel cell module, and directly contacting respective surfaces of the two plates that face away from one another with respective catalyst plates, and wherein there are no catalyst plates between the surfaces of the plates that face one another. In the '673 *Japanese application publication*, the molding material 19 joins together two different separators or electrodes 1, 2, not two plates forming a single electrode.

U.S. Patent No. 6,440,594 to *Kindler et al.* discloses an aerosol feed direct methanol fuel cell. In the discussion beginning near the bottom of column 14, *Kindler et al.* describes a fuel cell configuration involving stacked membrane electrode assemblies in which each membrane electrode assembly is sandwiched between a pair of flow-modifying plates which comprise biplates and endplates, respectively. *Kindler et al.* describes beginning in the second full paragraph of column 15 that the biplate is a two-sided separator preventing contact between the anode and cathode of the fuel cell. The discussion near the bottom of column 15 referring to Fig. 6 describes a fuel cell formed by joining an anode biplate and a cathode biplate.

The comments in the Official Action seem to indicate that *Kindler et al.*'s reference to a "biplate" is a disclosure of an electrode comprised of two plates. It is respectfully submitted that this is not the case. Rather, the reference in *Kindler et al.* to "a biplate" is merely a shorthand reference to a bipolar plate. That is, the reference in *Kindler et al.* to a "biplate" is not a disclosure of an electrode comprised of two separate plates, and is not a disclosure of an electrode comprised of two separate plates at least partially joined or held together by way of a seal element as claimed. This is apparent from the illustration in Fig. 6 of *Kindler et al.* which illustrates the "biplate." An even better illustration of this can be seen in other relevant patents naming *Kindler* as an inventor. In this regard, the Examiner's attention is directed to U.S. Patent No. 6,254,748. This patent describes and illustrates (see Fig. 5 of the '748 patent) biplates 304, 305. Between adjacent pairs of the biplates 304, 305 (or between a biplate and an adjacent endplate 312) a membrane electrode assembly 302 is sandwiched. As clearly illustrated in Fig. 5 of

this patent, the biplate is not formed of two separate plates at least partially joined or held together by a seal member, but rather is a single bipolar plate.

The Examiner's attention is also directed to the accompanying technical paper authored by the inventors named in the '594 *Kindler et al. patent* cited in the Official Action. This technical paper discusses direct methanol, liquid-feed fuel cell systems and also refers to biplates. The first few lines of the left column of page 776 of this paper makes clear that the term "biplate" is merely used as a shorthand reference for a bipolar plate.

It is thus respectfully submitted that *Kindler et al.* does not disclose a fuel cell module or fuel cell arrangement in which the electrode (i.e., the electrode directly contacted on opposite surfaces by respective catalyst plates) comprises two separate plates at least partially joined or held together by a common seal element as recited in the independent claims. Assuming one of ordinary skill in the art was for some reason motivated to utilize *Kindler et al.*'s bipolar plate or biplate in the fuel cell module disclosed in the '673 *Japanese application publication*, one would simply replace the separator 1 (or the separator 2) in the '673 *Japanese application publication* with *Kindler et al.*'s bipolar plate or biplate. The result would still not be a fuel cell module or fuel cell arrangement as recited in the independent claims in which an electrode is comprised of two separate plates at least partially joined or held together by a common seal element, with no catalyst plate between the two electrode-forming plates.

Accordingly, there exists no reason why one of ordinary skill in the art would have combined the disclosures in the '673 *Japanese application publication* and

Kindler et al. so as to arrive at the claimed fuel cell module, fuel cell arrangement and method recited in the independent claims.

The Official Action also sets forth a prior art rejection based on the discussion in paragraph [0005] of the present application in view of the disclosure in *Kindler, et al.* The discussion in paragraph [0005] of the present application refers to *European Application Publication No. 1 032 065* which discloses a fuel cell. The disclosed fuel cell includes individual cells 1 formed from bipolar plates 2, 3 and an interposed membrane electrode assembly 4. Each of the bipolar plates 2, 3 is provided with a groove 9 that receives a sealing element 10. This '065 *European application publication* lacks disclosure that each of the bipolar plates 2, 3 is comprised of a pair of separate plates at least partially joined or held together by a common seal member as recited in the independent claims of this application. Stated differently, the two bipolar plates 2, 3 cannot correspond to the claimed two separate plates forming the electrode as claimed because of the membrane electrode assembly 4 interposed between the bipolar plates. As discussed above, the independent claims in this application recite that there are no catalyst plates between the facing surfaces of the two plates forming the electrode.

Fig. 5B of the '065 *European application publication* shows a different version of the bipolar plate or electrode 3. Here, the bipolar plate or electrode 3 is provided with a bore 19. Seal elements 10 are positioned on opposite sides of the plate 3 and are interconnected to one another by way of the bore 19. However, the seal element 10, 10 does not at least partially join or hold together two separate plates forming an electrode of a fuel cell module or a fuel cell arrangement as claimed. Also, the seal element 10, 10 does not extend through an opening in each of two separate plates

as recited in independent Claims 21, 27 and 40, and does not encompass at least a portion of an outer end face of two separate plates while also extending onto the surfaces of the two plates that face away from one another as set forth in independent Claims 25 and 39.

In addition, as also discussed above, *Kindler et al.* does not disclose a fuel cell module in which an electrode is comprised of two separate plates at least partially joined or held together by a common seal element. Quite the contrary, *Kindler et al.* discloses nothing more than what is already described in the '065 *European application publication* -- namely an electrode in the form of a bipolar plate (biplate). Thus, a combination of the disclosures in the '065 *European application publication* (paragraph [0005] of the present application) considered together with the disclosure in *Kindler et al.* would not have suggested to one of ordinary skill in the art the fuel cell arrangement, fuel cell module and process recited in the independent claims of this application.

Another rejection set forth in the Official Action involves the '673 *Japanese application publication* in view of the disclosure in U.S. Patent No. 3,615,840 to *Wolfe, Jr.* As explained above, the '673 *Japanese application publication* does not disclose an electrode of a fuel cell module in which the electrode is comprised of a pair of separate plates at least partially joined or held together by a seal element as claimed.

The Official Action relies upon *Wolfe, Jr.* for its disclosure of a fuel cell in which the anode is preferably composed of a base stratum supporting a catalytic material. The Official Action goes on to note that the dictionary definition of "stratum" refers to one of a series of layers, levels or gradations in an order system. Based on

this dictionary definition, the Official Action interprets the term "stratum" as used in *Wolfe, Jr.* to refer to at least more than one plate or sheet in contact with one another. Even assuming this dictionary definition of "stratum" is consistent with what is intended by the disclosure in *Wolfe, Jr.*, this "stratum" is not an electrode comprised of two separate plates at least partially joined or held together by a common seal element as claimed. Thus, assuming there would have been a reason why one of ordinary skill in the art would have looked to replace the separator 1 (or separator 2) disclosed in the '673 *Japanese application publication* with the "stratum" construction described in *Wolfe, Jr.*, the result would not be a fuel cell module, fuel cell arrangement or process as recited in the independent claims of this application.

The last rejection of the independent claims set forth in the most recent Official Action is based on the discussion in paragraph [0005] of the present application ('065 *European application publication*) in view of the disclosure in *Wolfe, Jr.* As explained above, the '065 *European application publication* discussed in paragraph [0005] of the present application and *Wolfe, Jr.* fail to disclose a fuel cell module, a fuel cell arrangement or a process as recited in the independent claims in which an electrode is comprised of two separate plates at least partially joined or held together by a common seal element, wherein the electrode is such that there are no catalyst plates between the two electrode-forming plates. Accordingly, there exists no reason why one of ordinary skill in the art would combine the disclosures in the '065 *European application publication* and *Wolfe, Jr.* in a manner that would result in the claimed fuel cell module, fuel cell arrangement and process recited in the independent claims of this application.

For at least the reasons set forth above, it is respectfully submitted that all of the independent claims in this application are allowable.

As the dependent claims are allowable at least by virtue of their dependence upon allowable independent claims, a detailed discussion of the additional distinguishing aspects of the fuel cell arrangement and fuel cell module recited in the dependent claims is not set forth at this time.

Withdrawal of the rejections or record and allowance of this application are earnestly solicited.

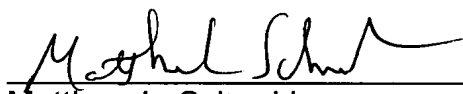
Should any questions arise in connection with this application or should the Examiner believe that a telephone conference with the undersigned would be helpful in resolving any remaining issues pertaining to this application the undersigned respectfully requests that he be contacted at the number indicated below.

Respectfully submitted,

BUCHANAN INGERSOLL & ROONEY PC

Date: October 3, 2007

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PROGRESS WITH THE DIRECT METHANOL LIQUID-FEED FUEL CELL SYSTEM

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ABSTRACT

The Direct Methanol, Liquid-Feed Fuel Cell with Proton Exchange Membrane (DMLFFC/PEM) technology offers a number of system advantages which on the whole compare favorably with the direct hydrogen PEM fuel cell system or the indirect fuel cell system. This paper summarizes progress in cell, stack, and system development based on the Direct Methanol, Liquid-Feed Fuel Cell concept.

INTRODUCTION

Several types of fuel cells that operate near ambient conditions are currently under development. The Hydrogen - Oxygen (H_2-O_2) or Hydrogen-Air (H_2 -Air) types include: phosphoric acid type being implemented in transportation applications, e.g., in buses, alkaline liquid-electrolyte types presently in use in the shuttle and the PEM (Proton Exchange Membrane) type under consideration for a number of applications.

Until recently, these fuel cells utilized gaseous H_2 directly or liquid fuel, e.g., methanol, reformed to hydrogen as the fuel. Pure O_2 or O_2 in air served as the oxidant. The use of H_2 as a fuel presents some practical problems, such as storage system weight and volume as well as handling and safety issues especially for consumer and transportation applications.

Indirect methanol fuel cells use reformers to convert methanol to H_2 , which is then fed to the H_2 -Air fuel cell. Methanol as a fuel offers ease of handling and storage, and potential infrastructure capability for distribution. Methanol also has a higher theoretical energy density than H_2 (~5kWh/l compared with 2.6kWh/l for H_2 liq.). Recharging can be accomplished simply by adding liquid methanol to extend range. However, the addition of the reformer to these H_2 -fueled fuel cells adds to complexity and cost as well as production undesirable pollutants such as CO. There is also some delay in response time.

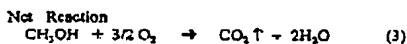
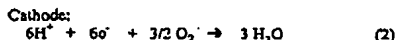
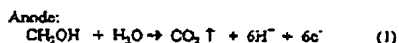
Direct oxidation of methanol in a PEM fuel cell is an attractive alternative in view of its simplicity from a systems point of view. The biggest payoffs for the DMLFFC/PEM system are the capability of efficient heat removal and thermal control through the circulating liquid and elimination of humidification required to avoid membrane dryout. These two characteristics have to be accounted for in the direct and indirect H_2 systems which impact their volume and mass.

THE BASIC CELL CONCEPT

Since 1991, the team at the JPL, University of Southern California (USC) and Giner Inc. has been developing new materials and processes associated with the direct methanol fuel cell, its stack and system design (1-7).

The DMLFFC/PEM allows the direct use of a aqueous, low concentration (3%), liquid methanol solution as the fuel. Air (O_2) is the oxidant. The methanol and water react directly in the anode chamber of the fuel cell to produce CO_2 and protons (H^+) that permeate the PEM and react with the oxygen at the cathode as shown in Figure 1.

The reactions are as follows:



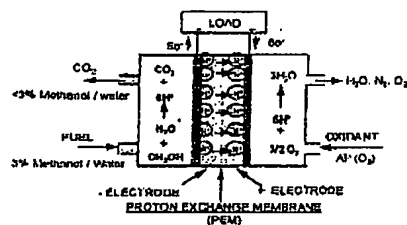


FIGURE 1. DMLFFC/PEM CELL DESIGN CONCEPT

The theoretical energy capability of methanol as given in the above reactions is ~ 3 kWh per liter based on 1.2V/cell. This is equivalent to 161 Ampere hours for every 32 g (~ 40 cm³) of methanol. The present performance is 34% of this or 1.4 kWh-hr per liter of methanol at 90°C using 20 psig air.

CELL PERFORMANCE

Several advances[3-5] have been made in the fabrication of membrane electrode assemblies for direct methanol fuel cells and the highest electrical performance observed is shown in Figs. 2 and 3.

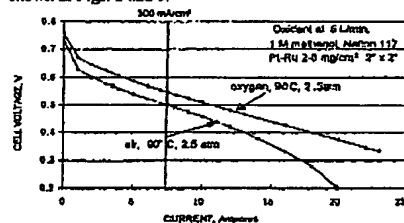


FIGURE 2. PERFORMANCE OF AIR AND O₂

This translates into power densities of 230 mW/cm² at 600 mA/cm² (equivalent to 100 A on a 153 cm² electrode) using air as compared to O₂ as the oxidant as shown in Figure 6.

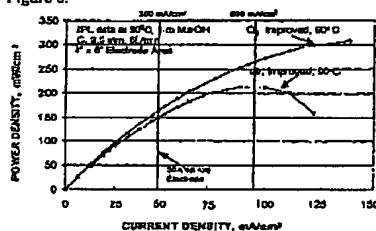


FIGURE 3. POWER PERFORMANCE OF THE DMLFFC / PEM

The PEM utilized in both H₂/air fuel cells and the DMLFFC/PEM is Nafion 117 which works well in both cases but is a high cost item. However, a disadvantage of the Nafion in the DMLFFC/PEM, is 'methanol crossover' i.e., methanol is dragged through the Nafion membrane along with the protons. Fortunately, the methanol and water react at the cathode producing the same CO₂ and H₂O as at the anode. Unfortunately, it does so without producing electrons. Until recently the methanol loss was 20%. Even with the 20% crossover the demonstrated stack efficiency is 34 %. In addition to the water produced in the reaction of H⁺ with O₂ and the methanol crossover which results in a reaction at the cathode with O₂ to produce water, there is a third source of water in the cathode chamber, i.e., water dragged through the membrane along with the protons and methanol.

A desired objective is to enhance the performance and reduce the crossover by developing a new membrane. A membrane material being developed at USC under the DARPA program appears to reduce crossover to less than 10%. An additional membrane material is also being developed at JPL under the sponsorship of DTL Energy. Both membranes are projected to be low cost.

There are significant advantages in reducing the methanol crossover in addition to improving efficiency. First and foremost it reduces the amount of water produced at the cathode. It also will tend to reduce polarization resulting in a higher voltage for the same current. A third advantage is the ability to increase the methanol concentration in the aqueous solution thus further increasing performance[4].

STACK DESIGN

The stack design, shown in Figure 4 comprises multiple cells, each cell being an MEA. The voltage, current and peak power requirements of the application will dictate the stack design, i.e., the number of cells and the active electrode area. These in turn determine the volume and mass of the fuel cell stack. The voltage output will be determined by the number of cells in series. The electrode area determines the current capability. Keep in mind that one of the advantages of this system is that small increases in electrode area can increase current capability substantially. The appropriate combination of voltage and current can either be supplied to the bus directly or can serve as input into a voltage converter. Both voltage and current are affected by temperature, quantity and rate of oxidant, and concentration and rate of fuel flow. Thus, a balance has to be achieved for each application.

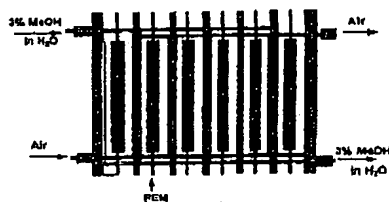


FIGURE 4. STACK DESIGN CONCEPT

Separating the cells from each other is a conductive and chemically stable bipolar plate (biplate). Its basic function is to provide the maximum conductivity and minimum resistance to flow of the fuel and oxidant. It serves three purposes: a) provides the electronic conduction from one cell to the other avoiding cell interconnects, b) provides a flow-field for the fuel mixture and air to flow through manifolds to the appropriate electrode surface, and c) transmits the force from the endplates to the electrodes to maintain conductivity. The design of the flow fields in the DMFC/PEM must consider the fact that the fuel is in the liquid state and that there is significant water flowing in the cathode chamber. The aqueous fuel mixture flows into the anode chamber. The unused aqueous methanol and the CO_2 produced at the anode flow from each cell into an exit manifold and then to an exit port. The water accumulated at the cathode side of each cell collects in the exit manifold and flows to the cathode exit port. The only product other than water is non-polluting CO_2 .

STACK PERFORMANCE

A five-cell stack was built at JPL during the period 1993-1996 for the purposes of understanding system related issues[7]. The performance of such a stack operating on ambient pressure air is shown in Fig. 5.

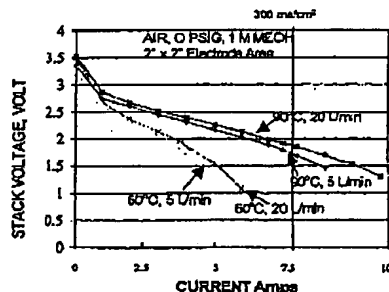


FIGURE 5. PERFORMANCE OF A 5 CELL STACK AT 80 AND 60°C AT AIR FLOW RATES OF 5 AND 20 LITERS PER MINUTE

For example, in a transportation application, water would be circulated through a radiator of the type presently in use in vehicles to maintain the constant operating temperature. Coincidentally, it is the same temperature ($\sim 90^\circ\text{C}$) that is used in vehicle radiators today. The effect of temperature on performance is given in Figure 5 for air for a five cell stack. Note that although the performance is lower, operating at a lower current will result in the same voltage output. This is the case for the two military applications described below.

PROJECTED PERFORMANCE

The present electrochemical efficiency (product of voltage efficiency and fuel efficiency) of the laboratory cells is about 34% when air is used as the oxidant, i.e., the voltage of 0.5 V together with the methanol crossover accounting for 20% of the current. It is expected that with a new membrane that restricts methanol crossover, higher methanol concentration, and improved electrode designs and catalysts, higher voltage and current, efficiencies approaching 50% levels are achievable, i.e., with 0.6V/cell and <10% crossover. USC has reported that a membrane is available that restricts methanol crossover to 5%. The projected performance is shown in Figure 6.

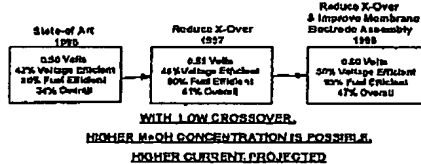


FIGURE 6. PROJECTED STACK PERFORMANCE LEVELS AT 300 mA/cm^2 AND 90°C

Finally, it is projected that the cost can also be reduced with the new low cost membranes, lower platinum loading and low cost bipolar plates all of which are under development. Further, since Platinum is recoverable, a system for trading in older fuel cell stacks is also possible thus lowering the cost.

THE DMFC/PEM SYSTEM

A schematic of the DMFC/PEM system is given in Figure 7. The system comprises the methanol / water subsystem and the air / water subsystem.

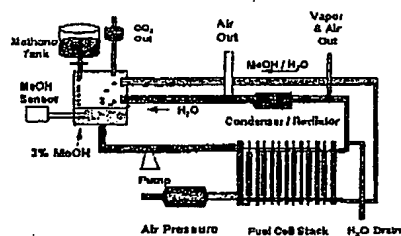


FIGURE 7. DMLFPC/PEM SYSTEM SCHEMATIC

The methanol / water subsystem provides the mechanism for mixing, maintaining, and feeding to the anode chamber and return of the unused aqueous methanol and CO_2 to the mixing tank where the CO_2 is released. The concentration of the methanol is controlled in the mixing chamber by a methanol sensor designed for that purpose. A small pump or pressure device is used to move the aqueous fuel into the anode manifold in the stack at a constant pressure and flow rate and return to the mixing tank. The ability to recirculate the fuel mixture is a means for optimizing the efficiency. Because the CO_2 is in the form of a gas it is easily separated from the liquid and released from the mixing chamber through a gas release port. Although there is a potential for droplets of aqueous methanol to accompany the gas release, a filter will be employed to prevent this from occurring.

The air / water subsystem includes the pressure and flow rate of air as well as the return of the unused air components and the water produced as described above. The system provides maximum power with O_2 , however, adequate performance is obtained with air as shown in Figure 5.

Although pressurized air is desired to maximize O_2 to the cathode, the system can provide adequate power for some applications by using a simple fan to provide air flow through the flow-field and across the cathode surface.

The fuel cell stack temperature will determine the state of water at the stack exit. The higher the temperature, the greater the fraction of water in the vapor phase. The balance point appears to be near 60°C . The water recovery process has to be capable of handling the balance and quantity of water returning to the mixing chamber for each application. Controls are needed for pumping fuel and air into the appropriate manifolds. Selection of these is dependent on the application. Sensors are required to monitor and control methanol concentration and temperature. A converter may be required to boost the voltage of a stack to the operating voltage. For example, a 110 V system using only fuel cells would require a 220 cell stack. The fuel and oxidant flow as well as continuity of the stack can be complex. As an alternative, a smaller

stack of 50 cells producing 25V can be boosted to 110V with a loss in efficiency of about 10%. The electrode area would have to be increased to account for the additional current and inefficiency. However, with $0.3\text{A}/\text{cm}^2$ the increase in area would be reasonable.

SYSTEM PERFORMANCE

A DMLFPC/PEM consisting of two parallel modular stacks of 12 cells each supplied by Oliner Inc. designed to produce 50W were assembled with off the shelf ancillary components. The system consisted of the following components:

- Fan Cooled Heat Exchanger and Radiator
- Air-Cooled Heat Exchanger for CO_2 Exhaust
- Vapor/Liquid Separator
- 500 ml Mixing Tank
- Liquid Pump and Air pump
- Thermal Switches on the Stacks
- Inlet and Outlet Temperature Indicators
- Temperature Monitor in Mixing Tank
- Methanol Sensor and Drip Control
- Computer Monitoring and control

The system was operated in a continuous mode for 140 minutes with heat up and steady state conditions. The system demonstrated mass and thermal balance over the two hour period over which it was operated. The system was able to operate continuously at a 0.3 molar methanol concentration. Further studies are in progress to determine the operating conditions and sizing for a 150 W system.

SUMMARY

Stack performance efficiency of 35% has been demonstrated with $>40\%$ realistically projected with lower cross-over membranes. Continuous system performance has been demonstrated by Direct Methanol, Liquid-Fed Fuel Cell/PEM system.

ACKNOWLEDGMENT

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REFERENCES:

1. S. Surampudi, S. R. Narayanan, E. Vamos, H. Frank and G. Halpert, A. Laconi, J. Kossek, G. K. Surya Prakash, and G. A. Olah, J. Power Sources, 47 377 (1994).
2. J. Kossek, C.C. Cropley, A. B. La Conti, G. Wilson, S. R. Narayanan, E. Vamos, S. Surampudi and H. Frank, Proceedings of the IECEC 1993, Volume 1, p. 1209.
3. S. R. Narayanan, A. Kindler, B. Jeffries-Nakamura, W. Chun, H. Frank, M. Smart, S. Surampudi and G. Halpert, Proceedings of the First International

Symposium on Proton Conducting Fuel Cells I, p.261-283, The Electrochemical Society, 1995 (Eds. S. Gottesfeld, G. Halpert and A. Landgrebe)

4. S. R. Narayanan, A. Kandler, B. Jeffries-Nakamura, W. Chun, H. Frank, M. Smart, T. I. Valdez, S. Surampudi, J. Kossek and C. Cropley, "Recent Advances in PEM Liquid Feed Direct Methanol Fuel Cells," Proceedings of the Eleventh Annual Battery Conference on Applications and Advances, Long Beach, CA, January 1996.
5. S. R. Narayanan, G. Halpert, W. Chun, D. Jeffries-Nakamura, T. I. Valdez, H. Frank and S. Surampudi,

Proceedings of the Power Sources Conference, Cherry Hill, New Jersey, June 1996.

6. S. R. Narayanan, W. Chun, B.-J. Nakamura, T. Valdez, H. Frank, S. Surampudi and G. Halpert, Presentation at the ECS meeting October 1996, San Antonio, TX.
7. T. I. Valdez, S. R. Narayanan, H. Frank and W. Chun, "Direct Methanol Fuel Cell for Portable Applications", p. 239-244, Proceedings of the Twelfth Annual Battery Conference on Applications and Advances, Long Beach, CA, January 1997.